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PHYSIOLOGIC EVALUATION OF THE L1/M1 ANTI-G STRAINING MANEUVER

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The voluntary informed consent of the subjects used in this research was obtained as required by Air Force Regulation 169-3.

This report has been reviewed by the Office of Public Affairs (PA) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication.

FOR THE COMMANDER

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13. ABSTRACT *(Maximum 200 words)*

The primary objective of this investigation was to test the use of a relatively simple (non-invasive) system to enable continuous monitoring of human muscle performance and reserve capability, as well as prediction of physical competence during repetitive execution of the L1/M1 anti-G straining maneuver (AGSM). Ten healthy volunteers tested this system while seated in a special mockup of an F-16 pilot seat. They were instructed to perform repetitive AGSMs, each at their maximal force capability. By comparing the initial Force Output and Electromyograph magnitudes with subsequent values, an index of muscle fatigue and reserve capability can be derived. Both F_O and EMG were found able to predict physical competence for performing AGSMs. Some subjects perceived their F_O to be maintained at the original maximum voluntary contraction (MVC) level due to their maximal effort contractions. However, it was clearly seen that F_O progressively deteriorated with muscle fatigue.

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PREFACE

This study was supported by the In-House Laboratory Independent Research (ILIR) Funds of the Armstrong Aerospace Medical Research Laboratory, Wright-Patterson Air Force Base, Ohio 45433-6573. Capt Tracy Gordon, former Flight Surgeon at AAMRL/BBS, initiated this study through the ILIR effort and monitored the project during his tenure at BBS (1985-1988). The utilization of humans for this project was authorized by the Air Force Human Use Committee (AAMRL Protocol 88-03), and by the Institutional Review Board Committee at Wright State University (Protocol HSP#704). This is a final report of the project, part of which was a dissertation submitted to Wright State University in partial fulfillment of the requirements for the degree of Master of Science in Aerospace Medicine. Ms Deer and Ms Sexton provided outstanding administrative support to enable publication of this project.

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INTRODUCTION

Pilots of high performance aircraft may encounter G-force loads as high as 9 Gz during combat maneuvers. This stress can put the pilot and aircraft at risk as high G environments (e.g., 4-9 Gz) can result in loss of consciousness due to reduced blood flow to the brain. To increase G-force tolerance, pilots typically perform the L1/M1 Anti-G Straining Maneuver (AGSM) while encountering high G forces. The AGSM utilizes intense static contractions of the arm, abdominal, and leg muscles to decrease fluid shifts that result in blood pooling in the lower-extremities, and to maintain blood pressure and cardiac output. However, frequent execution of AGSMs can be quite fatiguing, and lead to deterioration of performance and G-force tolerance. Unfortunately, pilots may not be capable of accurately gauging the degree of their ability to perform flight maneuvers because their maximal effort contractions result in lower force development with fatigue. Therefore, a system could be developed to constantly apprise them as to their muscular status for performing AGSMs, and to have realistic understanding of their physical reserve. This knowledge can improve pilot judgment, as well as flight safety and effectiveness.

The overall goal of this project is to develop a valid, reliable and easy to use (non-invasive) system for continuous monitoring of muscle performance and reserve capacity of pilots during AGSM activity while encountering high G-forces. The first phase of this study was reported in AAMRL-TR-88-047, A STRESS TEST TO EVALUATE THE PHYSICAL CAPACITY OF PERFORMING L1 ANTI-G STRAINING MANEUVERS. The primary objective of this present study was to construct a prototype system to test the feasibility of using this feedback technique. This prototype system monitors both force output and electromyographic activity of selected arm, abdominal and leg muscles to objectively indicate the degree of muscle fatigue during execution of repetitive AGSMs.

METHODS

Subjects

Ten volunteers between 18 and 30 years of age volunteered to participate in this study. Force-output (F_o) and surface electromyogram (EMG) were simultaneously monitored from the biceps/triceps, rectus abdominis and the quadriceps/hamstring muscle groups during execution of repetitive, maximal effort AGSMs.

Hardware Development

To monitor muscle force-output, transducers were fabricated by mounting strain-gauges upon stainless steel plates. The strain-gauges were coated with silicon rubber to prevent accidental damage and eliminate sharp edges. Attachment of the transducers around each muscle group was achieved through custom built straps with Velcro fasteners. Strain-gauge bridge amplifiers, signal conditioning and balancing circuits were developed for the force-output measurement system. To provide visual feedback of muscle force development to the subjects during AGSMs, the force signals from each muscle group were used to drive separate ten digit light emitting diode (LED) bar graph displays.

EMG amplifiers with the frequency response from 10 Hz to 1 KHz were developed to monitor the electromyographic activity of the muscles. Surface electrodes were used to detect these signals. The raw EMG was processed to produce root-mean-square (RMS) values, and the system has outputs for both the raw and the processed EMG.

Experimental Set-up

A schematic representation of the experimental set-up is shown in Figure 1. To simulate actual pilot body position, a mock-up of an F-16 seat was used for this study. Both force and EMG monitoring systems were used simultaneously to obtain F_o and EMG signals from the biceps, rectus abdominis and the quadriceps muscle groups. Visual feedback LEDs were placed in front of the subjects at close proximity for effective monitoring of muscle force. Outputs of the force transducer amplifier and EMG processor were fed into a strip recorder for continuous monitoring. These signals were also fed into the analog to digital converter (ADC) of a micro-computer for further analysis of the collected data. The illustrated impedance meter is for future studies of central hemodynamics (cardiac output and stroke volume).

Software Development

A computer program for an IBM-type computer with a 80386 micro-processor, was developed to acquire and analyze F_o and EMG data from the three monitored muscle groups during AGSM test protocols. Computer interrupt and timing routines were used to synchronize data collection throughout AGSM test periods. A flow-chart for the data acquisition system is shown in Figure 2. The basic performance testing protocol requires subjects to attempt 40 maximal effort AGSMs, each 5-sec in duration and followed by 5-sec of relaxation.

Data Collection Procedures

Prior to data collection, the strain-gauges were calibrated to known weights. They were then placed around the muscle groups to be monitored and maximal voluntary contractions (MVC) were performed to adjust the visual feedback LEDs to full scale. Thus, each digit of the ten digit LED displays represented 10% of the subject's maximal force output. Since subjects were instructed to achieve 100% F_o with each AGSM contraction, this arrangement provided a common reference factor (100% target) for all the subjects. It also provided an indication of the percentage of muscle fatigue and muscle reserve capacity.

Data were collected simultaneously on a strip-chart recorder and by a micro-computer in two phases. During the first phase, force and EMG data were collected during three MVCs (performed for 5-sec each with 1-min rest between contractions). This phase of data collection were used to set the individual's performance target (PT) when the muscles were fresh (not fatigued). During the second phase, the micro-computer took over the timing for the start and the stop of the maximal effort AGSMs while strip-chart recordings were continuously made at the speed of 2 mm/sec. For this, the micro-computer was programmed to produce a beep signal (sound) every 5 seconds to indicate the start and stop of the AGSMs. Interrupt routines were used to ensure accurate five second AGSM intervals, data collection intervals, and rest intervals. This process was repeated 40 times.

Data Analysis

In order to develop the data analysis system, the following terms are defined:

(1) Muscle reserve (M_R) is defined in this study as the normalized level of muscle activity (force output or EMG) during an AGSM, and is represented as:

$$M_R = 1/N \sum_{i=1}^{N} X_i \qquad (1)$$

where x_i represents the measured variable, F_o or EMG and i is an index of time.

(2) Performance target (PT) is defined as the ensemble average of the normalized level of pre-test muscle reserve baseline M_{Rb}, and is represented as:

$$PT = < M_{Rb} > \qquad (2)$$

this value (PT) determines 100% muscle reserve for the study session.

(3) Performance P is defined as:

$$P = (M_R/M_{Rb})*100 \tag{3}$$

(4) Performance index:

$$PI = P - 2/3*PT \tag{4}$$

The MVCs from the first phase of the study were averaged and normalized to determine the subject's 100% MVC value for the testing session: Equation 2. A performance target (PT) was then set for the individual so that he would try to achieve this value during the testing session. Each set of AGSM contraction data in the second phase was then averaged, normalized and a percentage of the muscle reserve baseline (M_{Rb}) was determined as shown in Equation 3 to quantify the individual's performance (P). The maximum number of AGSMs was set to 40. The performance index (PI), Equation 4, may be used to predict if an individual is likely to be able to continue the AGSMs. If the PI< 0 the subject is considered unable to continue the test.

RESULTS AND DISCUSSION

Figures 3 and 4 are sample plots of completed (number = 40 AGSMs) and discontinued (number < 40 AGSMs) testing sessions. The general trend of the F_o and EMG variables was similar in that the variables declined with muscle fatigue. It is interesting to note that when the PI was less than 60% of the performance target, the subject was not able to increase his/her subsequent performance no matter how hard he/she tried (Figure 3). Some of the subjects actually discontinued the exercise voluntarily after the AGSMs caused their PI to fall below 60% of their PT. Figure 4 confirms this algorithm. It was also observed that subjects perceived their F_o to be maintained at their original MVC level due to their maximal effort contractions. However, it was seen clearly that F_o progressively deteriorated with muscle fatigue. This suggests that the pilot's judgment about his physical capability may be impaired to the point he can no longer tolerate familiar G-force levels and unknowingly puts himself at high risk.

Table 1 is a list of means ($\bar{X}$), standard deviations (STD), and correlation coefficients (CORR), of F_o(1) and EMG(2) for the three muscle groups. The significantly high correlation coefficients indicate that either F_o or EMG could be used to derive the muscle reserve, and that the PI estimator is a consistent estimator. Note that these tests were conducted with volunteers who were not trained in this type of high level physical activity. More consistent results would be expected when the population is drawn mainly from personnel trained in performing the AGSM.

TABLE 1. MUSCLE GROUP DATA

TYPE	X1(lbs)	X2(RMS)	STD1	STD2	CORR. COEFF
Arm	77.4252	67.1739	12.9787	12.0785	0.7171
Stomach	81.9017	56.4362	15.5404	15.2928	0.7228
Leg	52.5000	47.3494	18.7760	13.7363	0.6999

Where X1 and X2 are the average values of the force and EMG outputs over 40 contractions; Std1 and Std2 are the standard deviations for the force and EMG outputs, respectively; and, Corr. Coeff. is the correlation coefficient between F_o and EMG.

SUGGESTIONS FOR FURTHER STUDIES

The consistency of the results obtained by this relatively simple monitoring system appears to justify further studies. One improvement that we recommend is to develop muscle force transducers that are easier and more convenient to use (e.g., built into the flight suit). Piezoelectric film transducers may be more suitable for this purpose as they do not require a rigid mounting as do the strain-gauges. Studies also need to be conducted to determine which muscle groups are most important for successful AGSM increases in G-force tolerance. This would permit the derivation of more appropriate formulas for predicting AGSM performance and G-force tolerance. It would also be desirable to monitor G-forces simultaneous with F_o (and EMG) to obtain a profile of a pilot's AGSM response to given G-force values. In this way, muscle fatigue and loss of G-force tolerance would be indicated by the pilot's inability to achieve appropriate AGSM force levels. A radiotelemetry system should also be developed to enable data acquisition and analysis at a remote location from the centrifuge or aircraft. Impedance techniques should also be used to determine central and peripheral hemodynamic responses to performing AGSMs.

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FIGURE 1. EQUIPMENT SET-UP

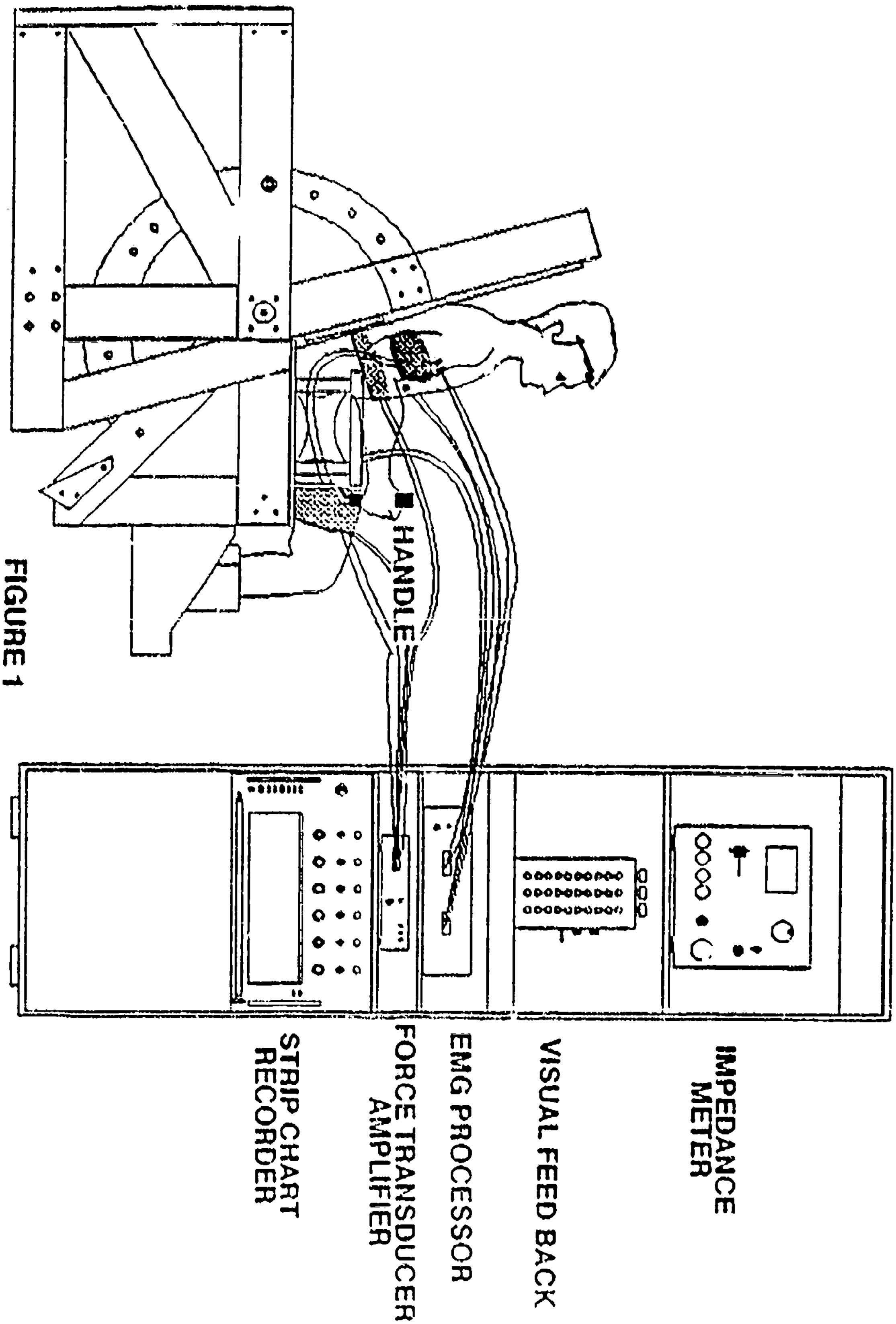

FIGURE 2. EXPERIMENTAL PROTOCOL

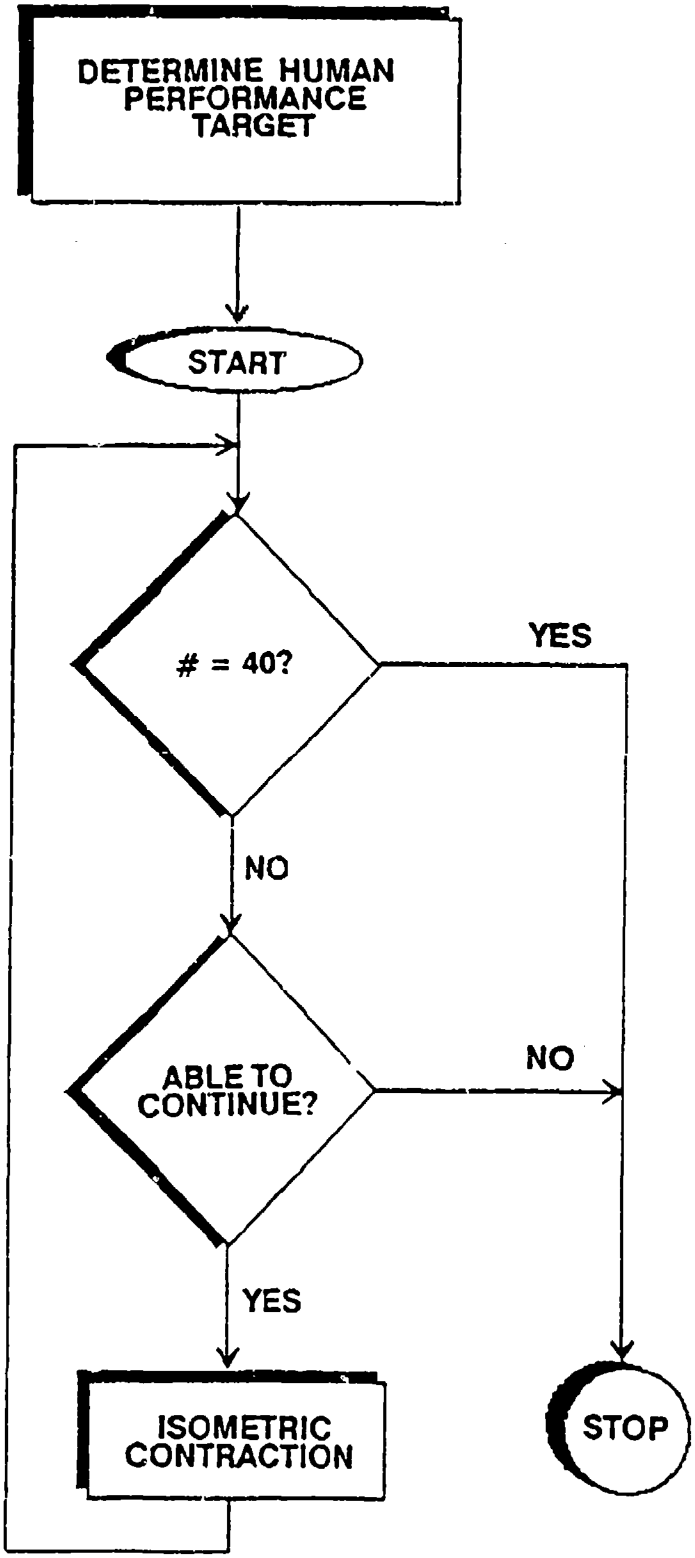

FIGURE 2

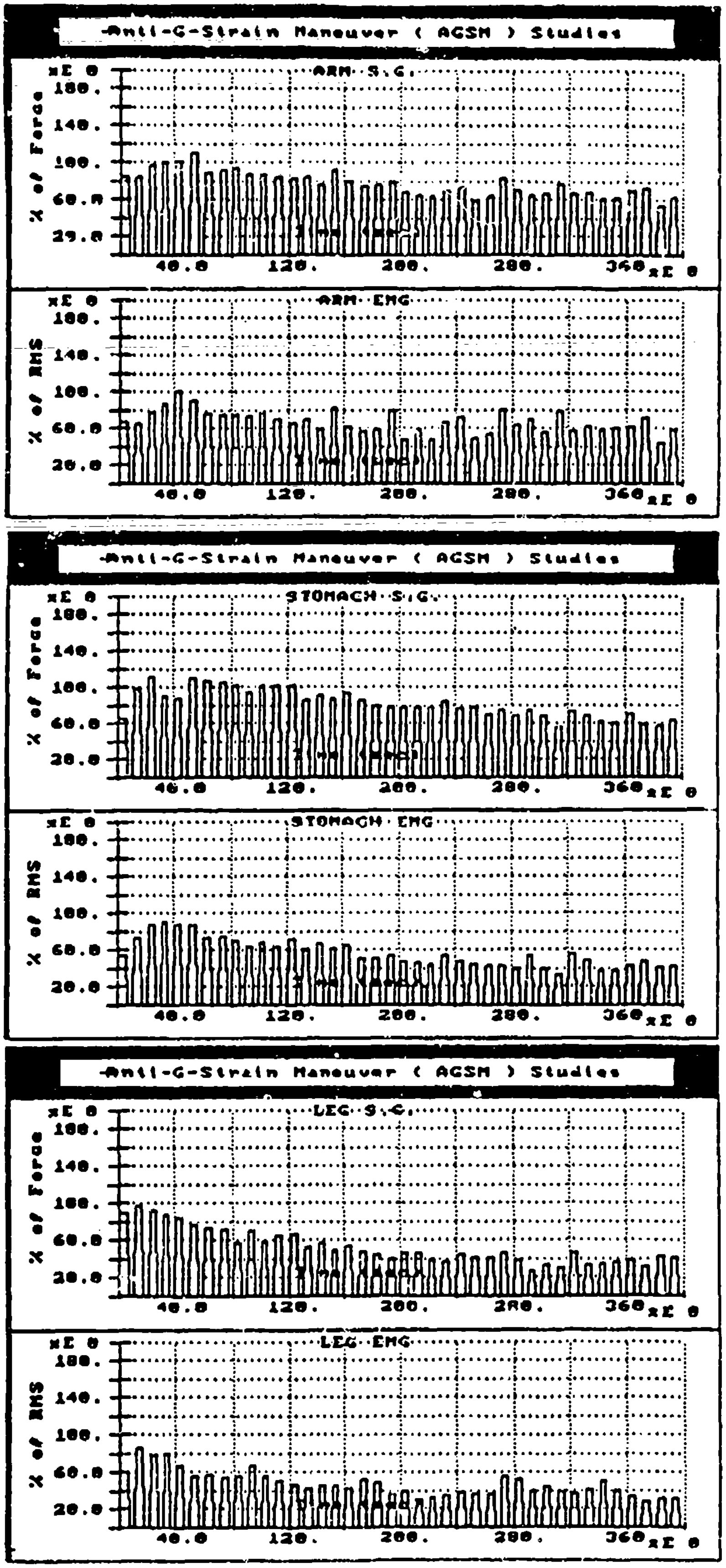

FIGURE 3. SAMPLE DATA PLOTS

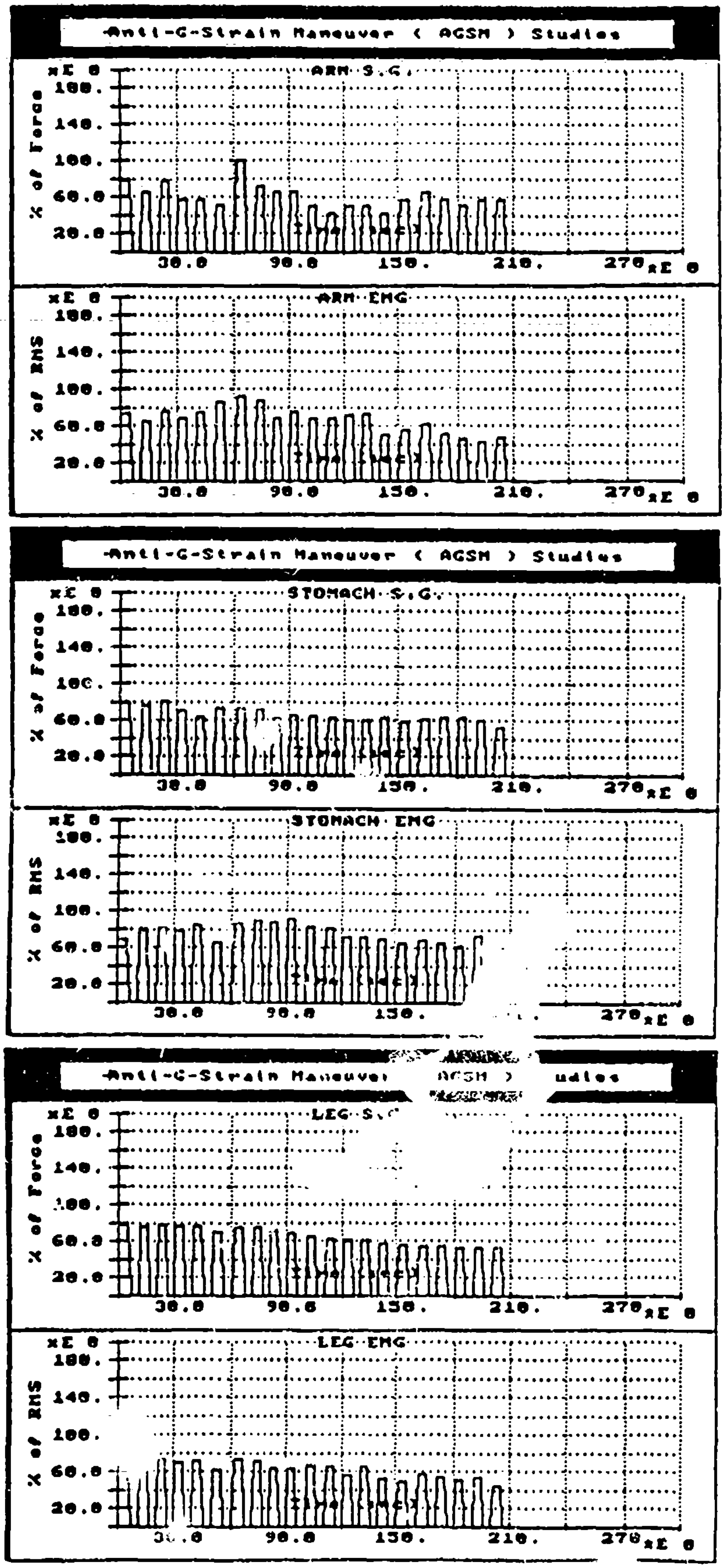

FIGURE 4. SAMPLE DATA PLOTS

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